Chapter 7
Choosing Among MHC Technologies

This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) organizes data collected or developed throughout the assessment of the baseline non-conveyorized electroless copper process and alternatives in a manner that facilitates decision-making. First, risk, competitiveness, and conservation data are summarized in Section 7.1. This information is used in Section 7.2 to assess the net benefits and costs to society of implementing an alternative as compared to the baseline. Section 7.3 provides summary profiles for the baseline and alternatives.

Information is presented for eight technologies for performing the making holes conductive (MHC) function. These technologies are electroless copper, carbon, conductive ink, conductive polymer, graphite, non-formaldehyde electroless copper, organic-palladium, and tin-palladium. All of these technologies are wet chemistry processes, except the conductive ink technology, which is a screen printing technology.[1] The wet chemistry processes can be operated using vertical, immersion-type, non-conveyorized equipment or horizontal, conveyorized equipment.[2] Table 7.1 presents the processes (alternatives and equipment configurations) evaluated in the CTSA.

Table 7.1 MHC Processes Evaluated in the CTSA[a]

MHC Technology	Equipment Configuration	
	Non-Conveyorized	Conveyorized
Electroless Copper (BASELINE)	✓	✓
Carbon		✓
Conductive Polymer		✓
Graphite		✓
Non-Formaldehyde Electroless Copper	✓	
Organic-Palladium	✓	✓
Tin-Palladium	✓	✓

[a] The human health and aquatic toxicity hazards and chemical safety hazards of the *conductive ink technology* were also evaluated, but risk was not characterized.

[1] Only limited analyses were performed on the conductive ink technology for two reasons: 1) the process is not applicable to multi-layer boards, which were the focus of the CTSA; and 2) sufficient data were not available to characterize the risk, cost, and energy and natural resources consumption of all of the relevant process steps (e.g., preparation of the screen for printing, the screen printing process itself, and screen reclamation).

[2] Conveyorized MHC equipment is a relatively new innovation in the industry, and is usually more efficient than non-conveyorized equipment. Many of the newer technologies are only being used with conveyorized equipment, while most facilities in the U.S. still use a non-conveyorized electroless copper process to perform the MHC function.

The results of the CTSA suggest that the alternatives not only have environmental and economic benefits compared to the non-conveyorized electroless copper process, but also perform the MHC function as well as the baseline. While there appears to be enough information to show that a switch away from traditional electroless copper processes has reduced risk benefits, there is not enough information to compare the alternatives to this process among themselves for all their environmental and health consequences. This is due to a lack of proprietary chemical data from some suppliers[3] and because toxicity values are not available for some chemicals. In addition, it is important to note that there are additional factors beyond those assessed in this CTSA which individual businesses may consider when choosing among alternatives. None of these sections make value judgements or recommend specific alternatives. The actual decision of whether or not to implement an alternative is made outside of the CTSA process.

7.1 RISK, COMPETITIVENESS, AND CONSERVATION DATA SUMMARY

Earlier sections of the CTSA evaluated the risk, performance, cost, and resource requirements of the baseline MHC technology as well as the alternatives. This section summarizes the findings associated with the analysis of MHC technologies. Relevant data include the following:

- Risk information: occupational health risks, public health risks, ecological hazards, and process safety concerns.
- Competitiveness information: technology performance, cost and regulatory status, and international information.
- Conservation information: energy and natural resource use.

Sections 7.1.1 through 7.1.3 present risk, competitiveness, and conservation summaries, respectively.

7.1.1 Risk Summary

This risk characterization uses a health-hazard based framework and a model (generic) facility approach to compare the health risks of one MHC process technology to the health risks associated with switching to an alternative technology. As much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each process alternative were aggregated from a number of sources, including printed wiring board (PWB) shops in the U.S. and abroad, supplier data, and input

[3] Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project. Atotech provided information on one proprietary ingredient. W.R. Grace was preparing to provide proprietary information on chemical ingredients in the conductive ink technology when it was determined that this information was no longer necessary because risk from the conductive ink technology could not be characterized. The other suppliers participating in the project (Enthone-OMI, MacDermid, and Shipley) declined to provide proprietary information.

from PWB manufacturers at project meetings. Thus, the model facility is not entirely representative of any one facility, and actual risk could vary substantially, depending on site-specific operating conditions and other factors.

When using the results of the risk characterization to compare health effects among alternatives, it is important to remember that it is a screening level rather than a comprehensive risk characterization, both because of the predefined scope of the assessment and because of exposure and hazard data limitations. It should also be noted that this approach does not result in any absolute estimates or measurements of risk, and even for comparative purposes there are several important uncertainties associated with this assessment (see Section 3.4).

The exposure assessment for the risk characterization used, whenever possible, a combination of central tendency and high-end assumptions (i.e., 90 percent of actual values are expected to be less) to yield an overall high-end exposure estimate. Some values used in the exposure calculations, however, are better characterized as "what-if,"[4] especially pertaining to bath concentrations, use of gloves, and process area ventilation rates for a model facility. Because some part of the exposure assessment for both inhalation and dermal exposures qualifies as a "what-if" descriptor, the entire assessment should be considered "what-if."

As with any risk characterization, there are a number of uncertainties involved in the measurement and selection of hazard data, and in the data, models, and scenarios used in the exposure assessment. Uncertainties arise both from factors common to all risk characterizations (e.g., extrapolation of hazard data from animals to humans, extrapolation from the high doses used in animal studies to lower doses to which humans may be exposed, missing toxicity data, including data on the cumulative or synergistic effects of chemical exposure), and other factors that relate to the scope of the risk characterization (e.g., the MHC characterization is a screening level characterization rather than a comprehensive risk assessment). Key uncertainties in this characterization include the following:

- The risk characterization of products supplied by Enthone-OMI, MacDermid, Shipley, and, to some degree, Atotech, is based on publicly-available bath chemistry data, which do not include the identity or concentrations of chemicals considered trade secrets by chemical suppliers.[5]
- The risk estimates for occupational dermal exposure are based on limited dermal toxicity data, using oral toxicity data with oral to dermal extrapolation when dermal toxicity data were unavailable. Coupled with the high uncertainty in estimating dermal absorption rates, this could result in either over- or under-estimates of exposure and risk.

[4] A "what-if" description represents an exposure estimate based on postulated questions, making assumptions based on limited data where the distribution is unknown.

[5] Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project for evaluation in the risk characterization. Atotech provided information on one proprietary ingredient. Risk results for proprietary ingredients in chemical products submitted by these suppliers, but not chemical identities or concentrations, are included in this CTSA.

- The risk characterization is based on modeled estimates of average, steady-state chemical concentrations in air, rather than actual monitoring data of average and peak air concentrations.
- The risk characterization does not account for any side reactions occurring in the baths, which could either underestimate exposures to toxic reaction products or overestimate exposures to toxic chemicals that react in the bath to form more benign chemicals.
- Due to resource constraints, the risk characterization does not address all types of exposures that could occur from MHC processes or the PWB industry, including short-term or long-term exposures from sudden releases due to fires, spills, or periodic releases.

The Risk Characterization section of the CTSA (Section 3.4) discusses the uncertainties in this characterization in detail.

Occupational Health Risks

Health risks to workers were estimated for inhalation exposure to vapors and aerosols from MHC baths and for dermal exposure to MHC bath chemicals. Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines. Dermal exposure estimates are based on the assumption that workers do not wear gloves[6] and that all non-conveyorized lines are operated by manual hoist. Dermal exposure to line operators on non-conveyorized lines could occur from routine line operation and maintenance (e.g., bath replacement, filter replacement, etc.). Dermal exposure to line operators on conveyorized lines was assumed to occur from bath maintenance activities alone.

Risk results indicate that alternatives to the non-conveyorized electroless copper process pose lower occupational risks due to reduced cancer risks and to the reduced number of inhalation and dermal risk concerns for the alternatives. However, there are occupational inhalation risk concerns for some chemicals in the non-formaldehyde electroless copper and tin-palladium non-conveyorized processes. In addition, there are occupational risk concerns for dermal contact with some chemicals in the conveyorized electroless copper process, the non-conveyorized non-formaldehyde electroless copper process, and tin-palladium and organic-palladium processes for either conveyorized or non-conveyorized equipment. Finally, occupational health risks could not be quantified for one or more of the chemicals used in each of the MHC technologies. This is due to the fact that proprietary chemicals in the baths were not identified by some suppliers and to missing toxicity or chemical property data for some chemicals known to be present in the baths.

Table 7.2 presents chemicals of concern for potential occupational risk from inhalation. Table 7.3 presents chemicals of concern for potential occupational risk from dermal contact.

[6] Many PWB manufacturers report that their employees routinely wear gloves in the process area. However, risk from dermal contact was estimated assuming workers do not wear gloves to account for those workers who do not wear proper personal protective equipment.

Table 7.2 MHC Chemicals of Concern for Potential Occupational Inhalation Risk

Chemical[a]	Non-Conveyorized Process[b]		
	Electroless Copper	Non-Formaldehyde Electroless Copper	Tin-Palladium
Alkene Diol	✔		
Copper Chloride	✔		
Ethanolamine	✔		✔
2-Ethoxyethanol	✔		
Ethylene Glycol	✔		
Formaldehyde	✔		
Formic Acid	✔		
Methanol	✔		
Sodium Hydroxide	✔		
Sulfuric Acid[c]	✔	✔	✔

[a] For technologies with more than one chemical supplier (e.g., electroless copper and tin-palladium), chemicals of concern that are present in all of the product lines evaluated are indicated in bold.
[b] Occupational inhalation exposure from conveyorized lines was assumed to be negligible.
[c] Sulfuric acid was listed on the MSDSs for all of the electroless copper lines evaluated and four of the five tin-palladium lines evaluated.

Table 7.3 MHC Chemicals of Concern for Potential Occupational Dermal Risk

Chemical[a]	Electroless Copper			Non-Formaldehyde Electroless Copper	Tin-Palladium			Organic-Palladium		
	Line Operator		Lab Tech (NC or C)	Line Operator (NC)	Line Operator		Lab Tech (NC or C)	Line Operator		Lab Tech (NC or C)
	NC	C			NC	C		NC	C	
Copper Chloride	✔	✔	✔		✔	✔	✔			
Fluoroboric Acid	✔	✔	✔		✔	✔	✔			
Formaldehyde	✔	✔								
Nitrogen Heterocycle	✔	✔								
Palladium[b]	✔	✔	✔		✔	✔	✔			
Palladium Chloride[b]					✔	✔	✔			
Palladium Salt								✔	✔	✔
Sodium Carboxylate	✔	✔								
Sodium Chlorite	✔	✔		✔						
Stannous Chloride[c]	✔			✔	✔	✔				
Tin Salt		✔								

[a] For technologies with more than one chemical supplier (e.g., electroless copper and tin-palladium), chemicals of concern that are present in all of the product lines evaluated are indicated in bold.
[b] Palladium or palladium chloride was listed on the MSDSs for three of the five tin-palladium lines evaluated. The MSDSs for the two other lines did not list a source of palladium. Palladium and palladium chloride are not listed on the MSDSs for all of the electroless copper lines evaluated.
[c] Stannous chloride was listed on the MSDSs for four of the five tin-palladium lines evaluated. The MSDSs for the remaining line did not list a source of tin. Stannous chloride is not listed on the MSDSs for all of the electroless copper lines evaluated.
NC: Non-Conveyorized.
C: Conveyorized.

The non-conveyorized electroless copper process contains the only non-proprietary chemical for which an occupational cancer risk has been estimated (for formaldehyde). Formaldehyde has been classified by EPA as Group B1, a Probable Human Carcinogen. The upper bound excess individual cancer risk estimate for line operators in the non-conveyorized electroless copper process from formaldehyde inhalation may be as high as one in 1,000, but may be 50 times less, or one in 50,000.[7] Risks to other workers were assumed to be proportional to the amount of time spent in the process area, which ranged from three percent to 61 percent of the risk for a line operator.

Inhalation cancer risk was also estimated for one proprietary chemical, alkyl oxide, in the non-conveyorized electroless copper process. The line operator inhalation exposure estimate for alkyl oxide results in an estimated upper bound excess individual life time cancer risk of 3×10^{-7} (one in three million) based on high end exposure. Cancer risks less than 1×10^{-6} (one in one million) are generally considered to be of low concern.

Additionally, dermal cancer risks were estimated for two proprietary chemicals, cyclic ether and alkyl oxide, in the graphite and electroless copper processes. For the conveyorized graphite process, the dermal cancer risks for a line operator may be as high as 8×10^{-8} (about one in ten million) for the alkyl oxide and 1×10^{-7} (one in ten million) for the cyclic ether. The upper bound cancer risks for a laboratory technician were much less than the cancer risks for a line operator. The cancer risks for a laboratory technician were 6×10^{-9} (one in 200 million) for alkyl oxide and 9×10^{-9} (one in 100 million) for cyclic ether.

For non-conveyorized electroless copper, the dermal cancer risks for the line operator may be as high as 4×10^{-7} (one in two million) for cyclic ether and 1×10^{-8} (one in 100 million) for alkyl oxide. The estimated upper bound cancer risks for a laboratory technician were much less than the cancer risks for a line operator. The estimated cancer risks for a laboratory technician were 9×10^{-9} (one in 100 million) for cyclic ether and 1×10^{-10} (one in ten billion) for alkyl oxide.

For conveyorized electroless copper, the dermal cancer risk for a line operator may be as high as 8×10^{-8} (about one in ten million) for cyclic ether and 4×10^{-9} (one in 200 million) for alkyl oxide. The estimated upper bound cancer risks for a laboratory technician were much less than the cancer risks for a line operator. The estimated cancer risks for a laboratory technician were 9×10^{-9} (one in 100 million) for cyclic ether and 1×10^{-10} (one in ten billion) for alkyl oxide.

Other non-proprietary chemicals in the MHC processes are suspected carcinogens. Dimethylformamide and carbon black have been determined by the International Agency for Research on Cancer (IARC) to possibly be carcinogenic to humans (IARC Group 2B). Like formaldehyde, the evidence for carcinogenic effects is based on animal data. However, unlike

[7] To provide further information on the possible variation of formaldehyde exposure and risk, an additional exposure estimate was provided in the Risk Characterization (Section 3.4) using average and median values (rather than high-end) as would be done for a central tendency exposure estimate. This results in approximately a 35-fold reduction in occupational formaldehyde exposure and risk from the estimates presented here.

formaldehyde, slope factors are not available for either chemical. There are potential cancer risks to workers from both chemicals, but they cannot be quantified. Dimethylformamide is used in the electroless copper process. Workplace exposures have been estimated but cancer potency and cancer risk are unknown. Carbon black is used in the carbon and conductive ink processes. Occupational exposure due to air emissions from the carbon baths in the carbon process is expected to be negligible because this process is typically conveyorized and enclosed. There may be some airborne carbon black, however, from the drying oven steps. Exposures from conductive ink were not characterized. One proprietary chemical used in the electroless copper process, trisodium acetate amine B, was determined to possibly be carcinogenic to humans but does not have an established slope factor.

Public Health Risks

Public health risk was estimated for inhalation exposure only for the general populace living near a facility. Environmental releases and risk from exposure to contaminated surface water were not quantified due to a lack of data; chemical constituents and concentrations in wastewater could not be adequately characterized. Public health risk estimates are based on the assumption that emissions from both conveyorized and non-conveyorized process configurations are steady-state and vented to the outside. Risk was not characterized for short-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other releases.

The risk indicators for ambient exposures to humans, although limited to airborne releases, indicate low concern from all MHC technologies for nearby residents. The upper bound excess individual cancer risk from formaldehyde inhalation for nearby residents from the non-conveyorized electroless copper process was estimated to be from approaching zero to 1×10^{-7} (one in ten million), and from approaching zero to 3×10^{-7} (one in three million) for the conveyorized electroless copper process. Formaldehyde has been classified by EPA as Group B1, a Probable Human Carcinogen. The risk characterization for ambient exposure to MHC chemicals also indicates low concern from the estimated air concentrations for chronic non-cancer effects. The upper bound excess individual cancer risk for nearby residents from alkyl oxide in the conveyorized graphite process was estimated to be from approaching zero to 9×10^{-11} (one in 11 billion); in the non-conveyorized electroless copper process from approaching zero to 1×10^{-11} (one in 100 billion); and in the conveyorized electroless copper process from approaching zero to 3×10^{-11} (one in 33 billion). All hazard quotients are less than one for ambient exposure to the general population, and all MOEs for ambient exposure are greater than 1,000 for all processes, indicating low concern from the estimated air concentrations for chronic non-cancer effects.

Ecological Hazards

The CTSA methodology typically evaluates ecological risks in terms of risks to aquatic organisms in streams that receive treated or untreated effluent from manufacturing processes. Stream concentrations of MHC chemicals were not available, however, and could not be estimated because of insufficient chemical characterization of constituents and their concentrations in facility wastewater.[8] To qualitatively assess risk to aquatic organisms, MHC chemicals were ranked based on aquatic toxicity values according to established EPA criteria for aquatic toxicity of high, moderate, or low concern (see Section 3.3.3).

Table 7.4 presents the number of MHC chemicals evaluated for each alternative, the number of chemicals in each alternative with aquatic toxicity of high, moderate, or low concern, the chemicals with the lowest concern concentration (CC) by alternative, and the bath concentrations of the chemicals with the lowest CC. The aquatic toxicity concern level could not be evaluated for some chemicals that have no measured aquatic toxicity data or established structure-activity relationships to estimate their aquatic toxicity. Aquatic toxicity rankings are based only on chemical toxicity to aquatic organisms, and are not an expression of risk.

Table 7.4 Aquatic Hazard Data

Alternative	No. of Chemicals Evaluated[a]	No. of Chemicals by Aquatic Hazard Concern Level[a]			Chemical with Lowest CC	Bath Concentration of Chemical With Lowest CC[b]
		High	Moderate	Low		
Electroless Copper	50[c]	9	19	21	copper sulfate (0.00002 mg/l)	4.8 to 12 g/l
Carbon	8[c]	2	2	3	copper sulfate (0.00002 mg/l)	5.0 g/l
Conductive Ink	11[c]	2	1	7	silver (0.000036 mg/l)	NA
Conductive Polymer	6	0	1	5	peroxymonosulfuric acid (0.030 mg/l)	26.85 g/l
Graphite	13	3	3	7	copper sulfate (0.00002 mg/l)	2.7 g/l
Non-Formaldehyde Electroless Copper	10	3	3	4	copper sulfate (0.00002 mg/l)	22 g/l
Organic-Palladium	7	2	3	2	sodium hypophosphite (0.006 mg/l)	75 g/l[d]
Tin-Palladium	26[c]	9	6	10	copper sulfate (0.00002 mg/l)	0.2 to 13 g/l

[a] This includes chemicals from both publicly-available and proprietary data. This indicates the number of unique chemicals; there is some overlap between public and proprietary lists for electroless copper. For technologies with more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals may not be present in any one product line.
[b] Bath concentrations are shown as a range for technologies supplied by more than one chemical supplier and are based on publicly-available bath chemistry data.
[c] No aquatic hazard data available for one chemical.
[d] Chemical is in microetch bath. Concentration in bath may be overestimated, because MSDS reports both chemicals in bath (sodium persulfate and sodium bisulfate) are present in concentrations < 75 percent (< 75 g/l).
NA: Not Applicable.

[8] There are well-documented copper pollution problems associated with discharges to surface waters and many of the MHC alternatives contain copper compounds. However, there were no data available to estimate the relative concentration of copper in different MHC line effluents. In addition, no data were available for surface water concentrations of other chemicals, especially chemicals in alternatives to electroless copper processes. Thus, risk to aquatic organisms were not characterized.

A CC is the concentration of a chemical in the aquatic environment which, if exceeded, may result in significant risk to aquatic organisms. CCs were determined by dividing acute or chronic toxicity values by an assessment factor (ranging from one to 1,000) that incorporates the uncertainty associated with toxicity data. CCs are discussed in more detail in Section 3.3.3.

The number of chemicals with a high aquatic hazard concern level include nine in the electroless copper process, two in carbon, two in conductive ink, none in conductive polymer, three in graphite, three in non-formaldehyde electroless copper, two in organic-palladium, and nine in tin-palladium. However, for technologies supplied by more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals of high aquatic toxicity concern may not be present in any one product line. The lowest CC is for copper sulfate, which is found in five of the MHC technology categories: carbon, electroless copper, graphite, non-formaldehyde electroless copper, and tin-palladium. Bath concentrations of copper sulfate vary, ranging from a high of 22 g/l for the non-formaldehyde electroless copper technology to a low of 0.2 g/l in one of the tin-palladium processes (and, based on MSDS data, not present in the conductive ink, organic-palladium, or conductive polymer processes).

Process Safety

Workers can be exposed to two types of hazards affecting occupational safety and health: chemical hazards and process hazards. Workers can be at risk through exposure to chemicals and because they work in proximity to automated equipment. In order to evaluate the chemical safety hazards of the various MHC technologies, MSDSs for chemical products used with each of the MHC technologies were reviewed. Table 7.5 summarizes the hazardous properties of MHC chemical products.

Table 7.5 Hazardous Properties of MHC Chemical Products

MHC Technology	No. of MSDSs Reviewed[b]	Number of Chemical Products with Hazardous Properties[a]					
		Flammable	Combustible	Explosive	Fire Hazard	Corrosive	Oxidizer
Electroless Copper	68	7	1	1	1	29	6
Carbon	11	7	0	0	0	5	2
Conductive Ink	5	0	0	5	0	0	0
Conductive Polymer[c]	8	1	0	0	0	5	0
Graphite	12	0	0	0	1	4	1
Non-Formaldehyde Electroless Copper	19	3	0	0	0	4	3
Organic-Palladium[c]	8	0	0	0	0	0	0
Tin-Palladium	38	2	1	1	1	12	0

[a] For technologies with more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals with hazardous properties may not be present in any one product line.
[b] Reflects the combined number of MSDSs for all product lines evaluated in a technology category.
[c] Based on German equivalent of MSDS, which may not have as stringent reporting requirements as U.S. MSDS.

Table 7.5 Hazardous Properties of MHC Chemical Products (cont.)

MHC Technology	No. of MSDSs Reviewed[b]	Number of Chemical Products with Hazardous Properties[a]					
		Reactive	Unstable	Sensitizer	Acute Health Hazard	Chronic Health Hazard	Eye Damage
Electroless Copper	68	16	1	0	14	10	34
Carbon	11	2	0	0	11	9	12
Conductive Ink	5	0	0	0	0	0	2
Conductive Polymer[c]	8	0	0	0	0	0	6
Graphite	12	0	1	0	8	4	4
Non-Formaldehyde Electroless Copper	19	4	0	0	9	5	7
Organic-Palladium[c]	8	0	1	0	0	0	4
Tin-Palladium	38	3	0	2	9	5	22

[a] For technologies with more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals with hazardous properties may not be present in any one product line.
[b] Reflects the combined number of MSDSs for all product lines evaluated in a technology category.
[c] Based on German equivalent of MSDS, which may not have as stringent reporting requirements as U.S. MSDS.

Other potential chemical hazards can occur because of hazardous decomposition of chemical products, or chemical product incompatibilities with other chemicals or materials. With few exceptions, most chemical products used in MHC technologies can decompose under specific conditions to form potentially hazardous chemicals. In addition, all of the MHC processes have chemical products with incompatibilities that can pose a threat to worker safety if the proper care is not taken to prevent such occurrences.

Work-related injuries from equipment, improper use of equipment, bypassing equipment safety features, failure to use personal protective equipment, and physical stresses that may appear gradually as a result of repetitive motion are all potential process safety hazards to workers. Regardless of the technology used, of critical importance is an effective and ongoing safety training program. Characteristics of an effective worker health and safety program include:

- An employee training program.
- Employee use of personal protective equipment.
- Proper chemical storage and handling.
- Safe equipment operating procedures.

Without appropriate training, the number of worker accidents and injuries is likely to increase, regardless of the technology used. A key management responsibility is to ensure that training is not compromised by pressure to meet production demands or by cost-cutting efforts.

7.1.2 Competitiveness Summary

The competitiveness summary provides information on basic issues traditionally important to the competitiveness of a business: the performance characteristics of its products relative to industry standards; the direct and indirect costs of manufacturing its products; its need or ability to comply with environmental regulations; and factors influencing world-wide markets for its products or technologies that may affect its competitiveness. The final evaluation of a technology involves considering these traditional competitiveness issues along with issues that business leaders now know are equally important competitiveness issues: the health and environmental impacts of alternative products, processes, and technologies.

Performance

The performance of the MHC technologies was tested using production run tests. In order to complete this evaluation, PWB panels, designed to meet industry “middle-of-the-road” technology, were manufactured at one facility, run through individual MHC lines at 26 facilities, then electroplated at one facility. The panels were electrically prescreened, followed by electrical stress testing and mechanical testing, in order to distinguish variability in the performance of the MHC interconnect. The test methods used to evaluate performance were intended to indicate characteristics of a technology’s performance, not to define parameters of performance or to substitute for thorough on-site testing; the study was intended to be a “snapshot” of the technologies. The Performance Demonstration was conducted with extensive input and participation from PWB manufacturers, their suppliers, and PWB testing laboratories.

The technologies tested included electroless copper (the baseline), carbon, conductive ink[9], conductive polymer, graphite, non-formaldehyde electroless copper, and palladium.[10] The test vehicle was a 24 x 18" 0.062" 8-layer panel. (See Section 4.1 for a detailed description of the test vehicle.) Each test site received three panels for processing through the MHC line.

Test sites were submitted by suppliers of the technologies, and included production facilities, testing facilities (beta sites), and supplier testing facilities. Because the test sites were not chosen randomly, the sample may not be representative of all PWB manufacturing facilities (although there is no specific reason to believe that they are not representative). In addition, the number of test sites for each technology ranged from one to ten. Due to the smaller number of test sites for some technologies, results for these technologies could more easily be due to chance than the results from technologies with more test sites. Statistical relevance could not be determined.

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[9] The conductive ink test panels were processed through the MHC process and sent for testing. The supplier of the technology felt that because the test vehicle used was incompatible with the capabilities of the conductive ink technology, the test results were not indicative of the capabilities of the technology. Therefore, the results of the conductive ink technology are not reported.

[10] The Performance Demonstration included both organic and tin-palladium processes in the overall palladium category.

Product performance for this study was divided into two functions: plated-through hole (PTH) cycles to failure and the integrity of the bond between the internal lands (post) and PTH (referred to as "post separation"). The PTH cycles to failure observed in this study is a function of both electrolytic plating and the MHC process. The results indicate that each MHC technology has the capability to achieve comparable (or superior) levels of performance to electroless copper. Post separation results indicated percentages of post separation that were unexpected by many members of the industry. It was apparent that all MHC technologies, including electroless copper, are susceptible to this type of failure.

Cost

Comparative costs were estimated using a hybrid cost model which combined traditional costs with simulation modeling and activity-based costs. The cost model was designed to determine the total cost of processing a specific amount of PWB through a fully operational MHC line, in this case, 350,000 surface square feet (ssf). Total costs were divided by the throughput (350,000 ssf) to determine a unit cost in $/ssf. The cost model did not estimate start-up costs for a facility switching to an MHC alternative or the cost of other process changes that may be required to implement an MHC alternative.

The cost components considered include capital costs (primary equipment, installation, and facility costs), materials costs (limited to chemical costs), utility costs (water, electricity, and natural gas costs), wastewater cost (limited to wastewater discharge cost), production costs (production labor and chemical transport costs), and maintenance costs (tank cleanup, bath setup, sampling and analysis, and filter replacement costs). Other cost components may contribute significantly to overall costs, but were not quantified because they could not be reliably estimated. These include wastewater treatment cost, sludge recycling and disposal cost, other solid waste disposal costs, and quality costs. However, Performance Demonstration results indicate that each MHC technology has the capability to achieve comparable levels of performance to electroless copper. Thus, quality costs are not expected to differ among the alternatives.

Table 7.6 presents results of the cost analysis, which indicate all of the alternatives are more economical than the non-conveyorized electroless copper process. In general, conveyorized processes cost less than non-conveyorized processes. Costs ranged from \$0.51/ssf for the baseline process to \$0.09/ssf for the conveyorized conductive polymer process. Seven process alternatives cost less than or equal to \$0.20/ssf (conveyorized carbon at \$0.18/ssf, conveyorized conductive polymer at \$0.09/ssf, conveyorized electroless copper at \$0.15/ssf, conveyorized organic-palladium at \$0.17/ssf, non-conveyorized organic-palladium at \$0.15/ssf, and conveyorized and non-conveyorized tin-palladium at \$0.12/ssf and \$0.14/ssf, respectively). Three processes cost more than \$0.20/ssf; all of these processes are non-conveyorized (non-conveyorized electroless copper at \$0.51/ssf, non-conveyorized non-formaldehyde electroless copper at \$0.40/ssf, and conveyorized graphite at \$0.22/ssf).

Table 7.6 Cost of MHC Technologies

Cost Category	Cost Components	Electroless Copper, non-conveyorized	Carbon, conveyorized	Conductive Polymer, conveyorized
Capital Cost	Primary Equipment	$64,000	$7,470	$5,560
	Installation	$11,200	$299	$0
	Facility	$8,690	$2,690	$2,250
Material Cost	Chemicals	$22,500	$32,900	$10,400
Utility Cost	Water	$6,540	$725	$410
	Electricity	$2,780	$836	$460
	Natural Gas	$0	$418	$0
Wastewater Cost	Wastewater Discharge	$13,700	$1,710	$965
Production Cost	Transportation of Material	$737	$446	$673
	Labor for Line Operation	$36,100	$10,200	$5,830
Maintenance Cost	Tank Cleanup	$5,430	$3,280	$4,960
	Bath Setup	$1,220	$740	$1,120
	Sampling and Testing	$4,260	$405	$436
	Filter Replacement	$2,800	$116	$376
Total Cost		**$180,000**	**$62,200**	**$33,400**
Unit Cost ($/ssf)		**$0.51**	**$0.18**	**$0.09**

Cost Category	Cost Components	Electroless Copper, conveyorized	Graphite, conveyorized	Non-Formaldehyde Electroless Copper, non-conveyorized
Capital Cost	Primary Equipment	$6,190	$3,580	$29,300
	Installation	$212	$131	$5,120
	Facility	$2,800	$1,090	$3,350
Material Cost	Chemicals	$22,600	$59,800	$69,600
Utility Cost	Water	$642	$251	$2,100
	Electricity	$669	$462	$1,310
	Natural Gas	$0	$145	$0
Wastewater Cost	Wastewater Discharge	$1,450	$612	$4,520
Production Cost	Transportation of Material	$883	$319	$682
	Labor for Line Operation	$7,230	$6,700	$16,200
Maintenance Cost	Tank Cleanup	$6,500	$2,350	$5,030
	Bath Setup	$1,460	$529	$1,130
	Sampling and Testing	$942	$316	$691
	Filter Replacement	$612	$901	$214
Total Cost		**$52,200**	**$77,200**	**$139,200**
Unit Cost ($/ssf)		**$0.15**	**$0.22**	**$0.40**

Table 7.6 Cost of MHC Technologies (cont.)

Cost Category	Cost Components	Organic-Palladium, conveyorized	Organic-Palladium, non-conveyorized
Capital Cost	Primary Equipment	$5,780	$4,160
	Installation	$356	$256
	Facility	$2,220	$1,100
Material Cost	Chemicals	$28,900	$27,000
Utility Cost	Water	$635	$758
	Electricity	$720	$325
	Natural Gas	$0	$0
Wastewater Cost	Wastewater Discharge	$1,510	$1,670
Production Cost	Transportation of Material	$1,260	$1,050
	Labor for Line Operation	$6,530	$7,190
Maintenance Cost	Tank Cleanup	$9,250	$7,710
	Bath Setup	$2,080	$1,740
	Sampling and Testing	$411	$288
	Filter Replacement	$271	$385
Total Cost		**$59,900**	**$53,700**
Unit Cost ($/ssf)		**$0.17**	**$0.15**

Cost Category	Cost Components	Tin-Palladium, conveyorized	Tin-Palladium, non-conveyorized
Capital Cost	Primary Equipment	$1,280	$4,760
	Installation	$205	$381
	Facility	$1,490	$1,910
Material Cost	Chemicals	$25,500	$22,300
Utility Cost	Water	$317	$1,010
	Electricity	$468	$635
	Natural Gas	$0	$0
Wastewater Cost	Wastewater Discharge	$754	$2,340
Production Cost	Transportation of Material	$537	$455
	Labor for Line Operation	$5,230	$10,700
Maintenance Cost	Tank Cleanup	$3,950	$3,350
	Bath Setup	$891	$755
	Sampling and Testing	$493	$916
	Filter Replacement	$332	$616
Total Cost		**$41,400**	**$50,100**
Unit Cost ($/ssf)		**$0.12**	**$0.14**

Chemical cost was the single largest component cost for nine of the ten processes. Equipment cost was the largest cost for the non-conveyorized electroless copper process. Three separate sensitivity analyses of the results indicated that chemical cost, production labor cost, and equipment cost have the greatest effect on the overall cost results.

Regulatory Status

Discharges of MHC chemicals may be restricted by federal, state or local air, water or solid waste regulations, and releases may be reportable under the federal Toxic Release Inventory program. Federal environmental regulations were reviewed to determine the federal regulatory status of MHC chemicals.[11] Table 7.7 lists the number of chemicals used in an MHC technology with federal environmental regulations restricting or requiring reporting of their discharges. Different chemical suppliers of a technology do not always use the same chemicals in their particular product lines. Thus, all of these chemicals may not be present in any one product line.

International Information

The total world market for PWBs is approximately $21 billion (EPA, 1995). The U.S. and Japan are the leading suppliers of PWBs, but Hong Kong, Singapore, Taiwan, and Korea are increasing their market share. Information on the use of MHC technologies worldwide was collected to assess whether global trends affect the competitiveness of an alternative.

The alternatives to the traditional electroless copper MHC process are in use in many countries. Most of the suppliers of these alternatives have manufacturing facilities located in countries to which they sell. Several suppliers indicated the market shares of the alternatives are increasing internationally quicker than they are increasing in the U.S. The cost-effectiveness of an alternative has been the main driver causing PWB manufacturers abroad to switch from an electroless copper process to one of the newer alternatives. In addition to the increased capacity and decreased labor requirements of some of the MHC alternatives over the electroless copper process, environmental concerns also affected the process choice. For instance, the rate at which an alternative consumes water and the presence or absence of strictly regulated chemicals are two factors which have a substantial effect on the cost-effectiveness of MHC alternatives abroad. While environmental regulations do not seem to be the primary forces leading toward the adoption of the newer alternatives, it appears that the companies that supply these alternatives are taking environmental regulations and concerns into consideration when designing alternatives.

[11] In some cases, state or local requirements may be more restrictive than federal requirements. However, due to resource limitations, only federal regulations were reviewed.

Table 7.7 Regulatory Status of MHC Technologies

MHC Technology	Number of Chemicals Subject to Applicable Regulation																
	CWA				SDWA		CAA			SARA 110	EPCRA		TSCA			RCRA Waste	
	304b	307a	311	Priority Pollutant	NPDWR	NSDWR	111	112b	112r		302a	313	8d HSDR	MTL	8a PAIR	P	U
Electroless Copper	4	4	13	8	4	5	8	8	2	6	6	13	2	4	3	2	4
Carbon	1	1	3	2	1	1				1		1					
Conductive Ink	2	2		2		1	5	3		1		2	2		3		1
Conductive Polymer			3				1				1	2					
Graphite	2	1	3	1	1	1	1		1	2	2	3					
Non-Formaldehyde Electroless Copper	1	1	5	1	1	1	1	1	1	3	3	4		1	1		
Organic-Palladium			2					1	1		1	1					
Tin-Palladium	2	2	7	2	3	3	3	1	1	6	3	6		3	3		1

Abbreviations and definitions:

CAA - Clean Air Act
CAA 111 - Standards of Performance for New Stationary Sources of Air Pollutants-Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
CWA - Clean Water Act
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CWA Priority Pollutants
EPCRA - Emergency Planning and Community Right-to-Know Act
EPCRA 302a - Extremely Hazardous Substances
EPCRA 313 - Toxic Chemical Release Inventory

RCRA - Resource Conservation and Recovery Act
RCRA P Waste - Listed acutely hazardous waste
RCRA U Waste - Listed hazardous waste
SARA - Superfund Amendments and Reauthorization Act
SARA 110 - Superfund Site Priority Contaminant
SDWA - Safe Drinking Water Act
SDWA NPDWR - National Primary Drinking Water Rules
SDWA NSDWR - National Secondary Drinking Water Rules
TSCA - Toxic Substances Control Act
TSCA 8d HSDR - Health & safety data reporting rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule

7.1.3 Resource Conservation Summary

Resources typically consumed by the operation of the MHC process include water used for rinsing panels, process chemicals used on the process line, energy used to heat process baths and power equipment, and wastewater treatment chemicals. A quantitative analysis of the energy and water consumption rates of the MHC process alternatives was performed to determine if implementing an alternative to the baseline process would reduce consumption of these resources during the manufacturing process. A quantitative analysis of both process chemical and treatment chemical consumption could not be performed due to the variability of factors that affect the consumption of these resources. Section 5.1 discusses the role the MHC process has in the consumption of these resources and the factors affecting the consumption rates.

The relative water and energy consumption rates of the MHC process alternatives were determined as follows:

- The daily water consumption rate and hourly energy consumption rate of each alternative were determined based on data collected from the IPC Workplace Practices Questionnaire.
- The operating time required to produce 350,000 ssf of PWB was determined using computer simulations models of each of the alternatives.
- The water and energy consumption rates per ssf of PWB were calculated based on the consumption rates and operating times.

Table 7.8 presents the results of these analyses.

Table 7.8 Energy and Water Consumption Rates of MHC Alternatives

Process Type	Water Consumption (gal/ssf)	Energy Consumption (Btu/ssf)
Electroless Copper, non-conveyorized (BASELINE)	11.7	573
Electroless Copper, conveyorized	1.15	138
Carbon, conveyorized	1.29	514
Conductive Polymer, conveyorized	0.73	94.7
Graphite, conveyorized	0.45	213
Non-Formaldehyde Electroless Copper, non-conveyorized	3.74	270
Organic-Palladium, non-conveyorized	1.35	66.9
Organic-Palladium, conveyorized	1.13	148
Tin-Palladium, non-conveyorized	1.80	131
Tin-Palladium, conveyorized	0.57	96.4

The energy consumption rates ranged from 66.9 Btu/ssf for the non-conveyorized organic-palladium process to 573 Btu/ssf for the non-conveyorized electroless copper process. The results indicate that all of the MHC alternatives are more energy efficient than the baseline process. They also indicate that for alternatives with both types of automation, the conveyorized version of the process is typically more energy efficient, with the notable exception of the organic-palladium process.

An analysis of the impacts directly resulting from the consumption of energy by the MHC process showed that the generation of the required energy has environmental impacts. Pollutants released to air, water, and soil can result in damage to both human health and the environment. The consumption of natural gas tends to result in releases to the air which contribute to odor, smog, and global warming, while the generation of electricity can result in pollutant releases to all media with a wide range of possible affects. Since all of the MHC alternatives consume less energy than the baseline, they all result in less pollutant releases to the environment.

Water consumption rates ranged from 0.45 gal/ssf for the graphite process to 11.7 gal/ssf for the non-conveyorized electroless copper process. In addition, results indicate that all of the alternatives consume significantly less water than the baseline process. Conveyorized processes were found to consume less water than non-conveyorized versions of the same process.

The rate of water consumption is directly related to the rate of wastewater generation. Most PWB facilities discharge process rinse water to an on-site wastewater treatment facility for pretreatment prior to discharge to a publicly-owned treatment works (POTW). A pollution prevention analysis identified a number of pollution prevention techniques that can be used to reduce rinse water consumption. These include use of more efficient rinse configurations, use of flow control technologies, and use of electronic sensors to monitor contaminant concentrations in rinse water. Further discussion of these and other pollution prevention techniques can be found in the Pollution Prevention section of this CTSA (Section 6.1) and in PWB Project Case Study 1 (EPA, 1995).